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APPLICATION THAT MET THE REQUIREMENTS TO BE GRANTED A
FILING DATE.

APPLICATION NUMBER: 60/373,332

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RELATED PCT APPLICATION NUMBER: PCT/US03/11854

By Authority of the
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04/17/02
JC857 U.S. PTO

4-18-02

A/Prov

Our Docket No.: S697.12-0063

PROVISIONAL PATENT APPLICATION

ENTITLED:

RAPID PROTOTYPING INJECTION MOLDING

11040 U.S. PTO
60/373332
04/17/02

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NAME

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ENCLOSURES

- ☒ Specification; Number of Pages 26
- ☒ Drawings; Number of Sheets 4
- ☒ A check in the amount of \$80.00.
- ☒ Applicant claims small entity status. See 37 C.F.R.1.27
- ☒ Fee Transmittal
- ☒ File Data Sheet

Respectfully submitted,

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Express Mail No.

Date of Deposit: April 17, 2002

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FEE TRANSMITTAL

Complete if Known

Application No.	
Filing Date	Herewith
First Named Inventor	S. Scott Crump
Group Art Unit	
Examiner Name	
Atty. Docket Number	S697.12-0063

Total Amount of Payment \$80.00

METHOD OF PAYMENT (Check One)

1. ☒ The Commissioner is hereby authorized to charge any additional fee required under 37 C.F.R. 1.16 and 1.17 and credit any over payments to Deposit Account No. 11-0982. Deposit Account Name: Kinney & Lange, P A

2. ☒ Check Enclosed

FEE CALCULATION

1. BASIC FILING FEE

Large Entity Fee Code	Large Entity Fee (\$)	Small Entity Fee Code	Small Entity Fee (\$)	Fee Description
101	740	201	370	[] Utility Filing Fee
106	330	208	165	[] Design Filing Fee
108	740	208	370	[] Reissue Filing Fee
114	160	214	80	<input checked="" type="checkbox"/> Prov Filing Fee
Subtotal (1) \$80.00				

2. EXTRA CLAIM FEES

	Number Claims	Prior	Extra	Fee from Below	Fee Paid
Total	-	=	X	=	-
Indep	-	=	X	=	-
Multiple Dependent Claims					
Insert 1 and 20, or number previously paid if greater, Reissue see below					
Large Entity Fee Code	Large Entity Fee (\$)	Small Entity Fee Code	Small Entity Fee (\$)	Description	
103	18	203	9	Claims in excess of 20	
102	84	202	42	Independent claims in excess of 3	
104	280	204	140	Multiple Dependent Claim	
109	84	209	42	Reissue Independent Claims Over Original Patent	
110	18	210	9	Reissue claims in excess of 20 and over original patent	
Subtotal (2) \$-0-					

FEE CALCULATION (Continued)

3. ADDITIONAL FEES

Large Entity Fee Code	Large Entity Fee (\$)	Small Entity Fee Code	Small Entity Fee (\$)	Fee Description	Fee paid
105	130	205	65	Surcharge - Late filing fee or oath	-
127	50	227	25	Surcharge - late provisional filing fee or cover sheet	-
139	130	139	130	Non-English specification	-
147	2,620	147	2,520	For Filing a Request for Reexamination	-
115	110	215	55	Extension for reply within first month	-
116	400	216	200	Extension for reply within second month	-
117	920	217	460	Extension for reply within third month	-
118	1,440	218	720	Extension for reply within fourth month	-
128	1,960	280	980	Extension for reply within fifth month	-
120	320	220	160	Filing a brief in support of an appeal	-
121	280	221	140	Request for oral hearing	-
148	110	248	55	Terminal Disclaimer Fee	-
140	110	240	55	Petition to revive - unavoidable	-
141	1,280	241	640	Petition to revive - unintentional	-
142	1,310	242	670	Utility/Reissue issue fee (inc advance copies)	-
143	490	243	280	Design issue fee (inc advance copies)	-
122	130	122	130	Petitions to the Commissioner	-
123	50	123	50	Petitions related to provisional applications	-
126	180	126	180	Submission of Information Disclosure Statement	-
581	40	581	40	Recording each patent assignment per property (times number of properties)	-
179	740	279	370	Request for Continued Examination (RCE)	-
Other fee (specify) _____					-
Subtotal (3) \$-0-					-

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Date 4/17/02 Deposit Account No. 11-0982

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Application Information

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Formal Drawings?:: No
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Docket Number:: S697.12-0063
Licensed US Govt. Agency::
Contract or Grant Numbers::
Secrecy Order in Parent Application?::

Representative Information

Representative Customer Number:: 00164

Continuity Information

This application is a::
> Application One::
Filing Date::
Patent Number::
which is a::
>> Application Two::
Filing Date::
Patent Number::

Prior Foreign Applications

Foreign Application One::
Filing Date::
Country::
Priority Claimed::

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RAPID PROTOTYPE INJECTION MOLDING
CROSS-REFERENCE TO RELATED APPLICATION(S)

This application is a continuation-in-part of application serial no. 10/019,160, filed October 19, 2001, which is a 371 of PCT/US00/10592 filed April 19, 2000, which is a non-provisional of provisional application serial no. 60/130,165 filed April 20, 1999.

BACKGROUND OF THE INVENTION

The present invention relates to prototyping of injection molded objects, and more particularly to an office-compatible method for rapidly making plastic injection molded prototypes parts.

In a typical injection molding process, plastic is injected at high pressures, extremely quickly, into a thermally conductive metal mold. The molded part is quickly cooled to a temperature at which it can be removed from the mold. The part is then quickly ejected from the mold so that another part can be made, and so that the part does not become stuck on the mold (due to shrink differential). Cooling of large parts continues on a fixture. The goals of production injection modeling are to produce a high quantity of high-quality parts in a short turn-around time. A thirty second cycle time or less for the making of each molded part is typical.

In order to produce a three-dimensional object in a typical injection molding process, it is necessary to prepare a mold tool that has a cavity which is complementary to the desired shape of the three-dimensional object. The mold tool generally consists of two opposing halves, which mate together to define the mold cavity. The mold tool is normally machined out of steel or other metal which is capable of withstanding high temperature and pressure when hot liquid is injected into the mold. In use, the mold tool is inserted into a frame of an injection molding machine, and held in place with high clamping forces to oppose pressure generated inside the mold. The time and skill required to prepare the mold tool are both significant. The machining must be done by skilled craftsmen, and includes the

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incorporation of a sprue through which the molding material is injected, a vent, cooling lines and ejector pins. Typically, this process involves placing an order with an outside vendor and waiting several weeks or months for delivery, at high cost.

5 Before undergoing the expense and long lead time associated with conventional metal mold manufacturing, it is desirable to produce a prototype of the part that will have similar characteristics to the production part. The goal is produce a prototype having characteristics sufficiently close to that of the desired final manufactured part so as to permit a close prediction of part performance.

10 Various additive process rapid prototyping (RP) technologies are commonly used to make prototype parts in the design stages of a part. These rapid prototyping technologies include fused deposition modeling (FDM), stereolithography (SLA), selective laser sintering (SLS), laminated object manufacturing (LOM) and jet technology. These additive process techniques produce prototypes useful for

15 evaluating the fit, form and function of a part design, to gain preliminary part approval and to accelerate product development. The strength of a final production part is not, however, replicated in prototypes created by these rapid prototyping techniques. The additive processes create layers, layered stress points and voids in the part resulting in a different internal stress structure than that of the

20 homogeneous injection-molded part. Additionally, many materials used in these processes are weak.

 Various methods have been developed for creating mold tools used to make prototype injection molded parts, which may be referred to as "bridge tooling" or "temporary tooling." A number of these methods utilize rapid

25 prototyping techniques, particularly, stereolithography. For example, U.S. Patent No. 5,439,622 describes the use of stereolithography to form a mold shell, which is then reinforced with an incompressible material and coated with a thermally conductive material. U.S. Patent No. 5,989,679 describes a mold tool formed by

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injecting a strengthening material into cavities within an object formed by stereolithography. U.S. Patent No. 5,952,018 describes a mold tool, including an ejection valve within the mold tool, formed by stereolithography. U.S. Patent No. 5,641,448 describes the making of a mold tool by depositing a metal coating onto
5 a plastic mold shell produced by stereolithography.

The use of rapid prototyping to create molds for use in processes other than injection molding are also known. For example, U.S. Patent No. 6,073,056 describes a mold built by stereolithography or fused deposition modeling used to form a vacuum cast part. U.S. Patent No. 6,103,156 describes the making
10 of a prototype part by pouring a thermoset into a mold formed by a rapid prototyping technique.

Techniques are also known which use a part formed a rapid prototyping process as a master mold pattern to create a prototype mold tool. For example, U.S. Patent No. 5,189,781 describes the use of a prototype part as the
15 pattern for making a sprayed metal mold. U.S. Patent No. 5,707,578 uses a prototype created by stereolithography as a master mold.

A commercial process known as the Swiftool™ process uses a prototype part, which may be made by a rapid prototyping technique, as a pattern for creating an epoxy mold. The process takes several days. Another commercial
20 process known as 3D Keltool® makes bridge tooling in a period of several days in a metal-powder sintering process, starting from a master pattern made by stereolithography. Yet another commercial system called AIM™ builds mold tools by stereolithography using UV-sensitive materials.

There is a need for a more rapid, easy to use and low cost method
25 of creating a small number of prototype injection molded parts, that is compatible with an office environment.

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BRIEF SUMMARY OF THE INVENTION

The present invention is a method and apparatus for making a prototype plastic injection molded part using a non-conductive plastic mold tool that may be built using a rapid prototyping technique. The prototype part is made from a production thermoplastic material which allows an assessment of the strength of a production part. The production thermoplastic is injected into a mold cavity of the mold tool by an extrusion head at a controlled, low pressure, under isothermic conditions to form the prototype part. The extrusion head may be a filament pump (*i.e.*, an FDM head), a piston pump, a screw pump, or other extruder.

10 The prototype part is cooled in the mold cavity to approximately room temperature. The production thermoplastic and the plastic that forms the mold tool are selected so as to have approximately the same shrink characteristics upon cooling. A fused deposition rapid prototyping machine may be the apparatus used to perform the injection.

15 In a preferred embodiment, the mold tool is made by a fused deposition modeling technique. In one embodiment, the mold tool is built in two or more portions, wherein layers of thermally solidifiable non-conductive material are deposited in a predetermined pattern according to computer file data representing the mold shape. Each mold portion includes a mold surface, a mating surface, and a base which supports the mold and mating surfaces. Together the mold portions define the mold cavity. A sprue channel and alignment holes are either formed into the mold tool as it is built, or machined into the mold tool after it is built. A vent channel may likewise be built or machined into the mold tool, or, the build process itself may be designed to result in the mold tool having an open-cell matrix so as to vent the tool. Optionally, the mold surfaces and mating surfaces may be smoothed by a vapor smoothing process to remove unintentional ridges in the surfaces. In an alternate embodiment, the mold tool is made from a soluble material and has a single-piece construction.

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Using the present invention, an injection molded prototype part can be made from a digital representation of the part within 24 hours by an engineer in an office environment. The design engineer is empowered to build injection modeled parts from CAD files, similar to how rapid prototyping empowered the design engineer to build prototypes from CAD files.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a top plan view of two mold portions of an exemplary mold tool for use with the present invention produced by fused deposition modeling

Figure 2 is a sectional view of the mold portions of FIG. 1, taken along a line 2-2 of FIG. 1 and mated together to define a mold cavity.

Figure 3 is a schematic illustration of a rapid prototyping injection molding machine according to the present invention.

Figure 4 is a flow diagram of the process of making a prototype injection molded part in accordance with the present invention, using a mold tool made by fused deposition modeling.

DETAILED DESCRIPTION

The method and apparatus of the present invention builds a prototype injection molded part using a non-conductive plastic mold tool, which is preferably built using a rapid prototyping technique. The injection is done by extruding thermoplastic material as a liquified ribbon of material from an extruder of the type used in a fused deposition modeling machine. The mold tool is heated to approximately the temperature of the extruded material, and extruded material is injected into a mold cavity of the mold tool at a controlled, low pressure. After the mold cavity is filled, the prototype part thus created is allowed to cool inside of the mold tool. The prototype part is made from a production thermoplastic material which allows an assessment of the strength of a production part. A fused deposition modeling machine may be used for the prototype injection molding apparatus.

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In contrast to manufacturing injection molding processes, the present invention uses low pressures, low flow rates and slow cycle times, allowing the use of a non-reinforced plastic mold tool and providing a safe process compatible with office use. Using the present invention, an injection-molded prototype can be
5 formed from a digital representation of the desired prototype part within about a 24-hour time period, by an engineer in an office-friendly environment.

Figure 1 shows two halves of an exemplary mold tool 10 for use in carrying out the present invention. The exemplary mold tool is the subject of a co-pending provisional patent application entitled "Layered Deposition Bridge
10 Tooling," filed on even date herewith. A first portion 12 of mold tool 10 includes a recessed mold surface 14 corresponding to the shape of a first half of a desired prototype molded part. A second portion 16 of mold tool 10 includes a recessed mold surface 18 corresponding to the shape of a second half of the desired prototype molded part. The mold portions 12 and 16 each have a mating surface
15 17 and a base 20 shown in FIG. 2, which supports the mold surfaces 14 and 18 and the mating surfaces 17. When the mating surfaces 17 of the mold portions 12 and 16 are mated together as shown in FIG. 2, the mold surfaces 14 and 18 define a mold cavity 19, which has the shape of the desired prototype part. For prototype molded parts that have interior cavities, the mold tool 10 further comprises a mold
20 core.

The mold portions 12 and 16 each also include a sprue channel 22, a vent channel 24, and four alignment holes 26. The sprue channels 22 allow for the placement of a sprue which will be inserted in a final assembly of the mold tool 10, providing a path for the injection of molten plastic into the mold cavity 19. The
25 vent channels 24 together form a passage for the venting of gas from the mold cavity 19 when the mold tool 10 is assembled. The alignment holes 26 receive screws or pins, which align and hold together the mold tool portions 12 and 16 in assembly of the mold tool 10.

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In an alternate embodiment, a mold tool is made from a soluble modeling material and has a single-piece construction. The soluble material permits a single-piece construction, as the mold tool may be dissolved from a prototype part after the part is formed. In contrast, a mold tool made from an insoluble material is removed from a prototype part by mechanically disengaging the mold portions. A suitable soluble modeling material is an alkali-soluble material comprising a base polymer containing a carboxylic acid, and a plasticizer. The base polymer comprises a first comonomer (which contains carboxylic acid) and a second comonomer that is polymerized with the first comonomer to provide thermal and toughness properties suitable for fused deposition modeling. A preferred base polymer is comprised of methacrylic acid as the first comonomer and an alkyl methacrylate (e.g., methyl, ethyl, propyl or butyl methacrylate, and combinations thereof), preferably methyl methacrylate, as the second comonomer. A desirable amount of the acid-containing first comonomer is 15-60 weight percent of the base polymer. The base polymer is plasticized to attain rheological properties desired for the modeling process. Most preferably, the alkali-soluble thermoplastic material contains between about 84 weight percent and 74 weight percent of the base polymer and contains between about 16 weight percent and 26 weight percent of the plasticizer, and has a melt flow index of between about 5 g/10 minutes and 10 g/10 minutes under a load of 1.2 kg at 230 °C. A mold tool made from the alkali-soluble material is removed from the prototype part by placing the mold tool containing the part in an alkaline bath. The alkali-soluble modeling material is the subject of co-pending U.S. Patent application serial no.10/019,160, which is hereby incorporated by reference as if set forth fully herein.

The mold tool for use in the present invention is preferably built by a rapid prototyping process, such as by fused deposition modeling, from computer file data representing the mold tool. The computer file data is derived from information available on the desired prototype molded part. For example, typically,

the part is designed using a computer-aided design (CAD) system, and corresponding information relating to the outline of the part is derivable from a CAD file defining the desired part. A computer program designs the mold portions in accordance with the outline of the desired part, as the inverse of the desired part shape. For instance, software available from Moldflow Corporation, will design the mold portions in this manner. A further software program "slices" the computer representation of the mold portions into horizontal layers.

Fused deposition modeling builds up three-dimensional objects, such as the mold tool of the present invention, in layers by extruding molten modeling material in a predetermined pattern according to the computer file data representing the mold tool. The modeling machine extrudes the roads of modeling material layer-by-layer, with each extruded road having a thickness equal to the height of a slice. The extruded material fuses to previously deposited material and solidifies upon a drop in temperature to form the mold portions. The mold portions may be built simultaneously in the modeling machine, or one at a time. In a preferred embodiment, the mold portions 12 and 16 are built from a polyphenylsulfone resin on a Stratasys® Titan™ FDM® fused deposition modeling machine.

The sprue channels 22, the vent channels 24 and the alignment holes 26 are preferably formed into the mold portions 12 and 16 as they are built. This can be done by including such features in the computer file data representing the mold tool 10. Alternatively, a sprue channel, vent channel and/or alignment holes may be machined into the mold portions 12 and 16 after they are built. The channels 22 and 24 and the alignment holes 26 shown in the exemplary mold tool 10 are merely one example of the placement and design of such features. Alternative designs include vertical orientation of the channels 22 and 24, and forming a single sprue channel or vent channel within one or the other of mold portions 12 and 16.

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The need for a vent channel in the mold tool 10 may be avoided by controlling the extrusion pattern of the roads so that the mold tool 10 has an inherent porosity providing an open-cell matrix sufficient to vent gas from the mold cavity 19. Controlled-porosity fused deposition modeling is taught in U.S. Patent
5 No. 5,653,925.

The exemplary mold tool 10 is formed from a non-conductive thermoplastic material that will sustain the temperature and pressure of the injection molding process, so as to produce at least one prototype plastic injection molded part. An exemplary thermoplastic comprises at least 50 weight percent of a
10 thermoplastic selected from the group consisting of polycarbonate, polystyrene, acrylics, amorphous polyamides, polyesters, polyphenylsulfone, polysulfone, polyphenylene ether, nylon, PEEK, PEAK, poly(2-ethyl-2-oxazoline), and blends thereof. A particularly preferred thermoplastic for use in creating a mold tool by fused deposition modeling is a polyphenylsulfone-based resin.

FIG. 3 shows a rapid prototype injection molding apparatus 30 in
15 accordance with the present invention, in the process of making a prototype part. The apparatus 30 comprises a movable extrusion head 32 having a dispensing tip 34, a material supply 36, a controller 38, a base 40, and a hollow sprue 42. The mold tool 10 is assembled and positioned in the apparatus 30. Prior to assembly of
20 the mold tool 10, the mold surfaces 14 and 18 are created with a release agent that facilitates removal of a completed part from the mold tool 10. Suitable release agents include dry film lubricants, and others that will be recognized by those skilled in the art. The mold tool 10 sits on top of the base 40. Sprue 42 is placed in the sprue channels 22, such the a dispensing end of the sprue 42 is directed into
25 the mold cavity 19. The sprue 42 has an entry 44 at a top end thereof, designed to mate with the downward-facing extrusion head tip 34. The sprue entry 44 receives and attached to the extrusion head tip 34, thereby providing a flow path from the extrusion head 32 into the mold cavity 19. Also, a pressure transducer is placed in

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the sprue to monitor pressure in the mold cavity so that a predetermined pressure may be maintained.

5 The extrusion head 32 receives a supply of production thermoplastic material for creating the molded prototype part from the material supply 36, at a rate controlled by the controller 38. The extrusion head 32 may be of any type which receives a thermoplastic material and dispenses the material in a molten state through a dispensing tip. Suitable extrusion heads have been developed for fused deposition modeling, and include a liquifier pump, a piston pump and a screw pump. Each of these extrusion heads developed for three-dimensional modeling
10 receives a feedstock of thermoplastic in solid form, and heats the thermoplastic material to a desired temperature for extrusion.

Where the extrusion head 32 is a liquifier pump, the material supply 36 comprises spooled flexible filament and the extrusion head 32 carries a set of feed rollers for advancing the filament into the extrusion head at a controlled rate.
15 Liquifier pumps are disclosed, for example, in U.S. Patent No. 6,004,124. Where the extrusion head 32 is a piston pump, the material supply 36 comprises cylindrical feed rods of thermoplastic material fed in a batch process. A piston pump extrusion head is disclosed in U.S. Patent No. 6,067,480. Where the extrusion head 32 is a screw pump, the material supply 36 comprises pellets of thermoplastic material.
20 A screw pump extrusion head is disclosed, for example, in U.S. Patent No. 5,312,224. Two-stage extrusion heads are also known in the art, and can also be used in practice of the present invention. A extrusion pump is disclosed in U.S. Patent No. 5,764,521, wherein the feedstock received from material supply 36 is pressurized in a two-stage process which may take various forms.

25 The extrusion head 32 may include an ultrasonic vibrator for creating a thixotropic flow at the dispensing tip exit, such as is disclosed in U.S. Patent 5,121,329. The ultrasonic energy would reduce the injection pressure while increasing the flow rate of the production thermoplastic.

For the production of a prototype part, production thermoplastic is provided from the material supply 36 to the extrusion head 32, which heats the production thermoplastic to an extrusion temperature and dispenses molten extruded material 46 through sprue 42 and into the mold cavity 19. Production thermoplastics that may be used in the present invention include, without limitation, ABS, polycarbonate, polystyrene, acrylics, amorphous polyamides, polyesters, polyphenylsulfone, polyphenylene ether, nylon, PEEK, PEAK, and blends thereof. Shrink characteristics of the mold tool plastic are matched to the shrink characteristics of the production thermoplastic, which can be achieved by using amorphous thermoplastics. Also, the production thermoplastic must have a heat deflection temperature lower than a heat deflection temperature of the plastic which forms the mold tool, so that the mold tool will maintain its shape.

FIG. 4 shows a flow diagram which summarizes the method of producing a prototype injection molded part in accordance with the present invention, using a mold tool made by fused deposition modeling. A CAD tool is used to generate computer file data representing a mold tool, in step 40. The data is provided to a fused deposition modeling machine, in step 42. The mold tool is built in the fused deposition modeling machine, in layers defined by the computer file data, in step 44. In an optional step 46, the mold surfaces and/or mating surfaces of the mold tool are smoothed to remove ridges unintentionally created in the formation of the mold tool. In a preferred embodiment, the smoothing is done by a vaporized solvent in a vapor smoothing process, such as is disclosed in a co-pending provisional patent application entitled "Smoothing Method For Layered Deposition Modeling", filed on even date herewith and incorporated by reference as is set forth fully herein (copy attached hereto as Appendix A). Vapor smoothing will also serve to seal the surfaces of the mold tool. Alternatively, smoothing can be done by applying a liquid solvent. Other alternative smoothing techniques include sanding, grinding, and thermal ironing.

The mold surfaces of the mold tool are then coated with a release agent, in a step 48 (a soluble mold tool may not need a release agent). If needed, sprue and vent channels and alignment holes are machined into the mold tool prior to step 48. The mold tool is assembled in an prototype injection molding apparatus according to the present invention, without the addition of any reinforcement fill material or layers, in a step 50. The fused deposition modeling used to build the mold tool may be used also as the prototype injection molding apparatus. In step 50, the sprue is positioned in the mold tool and attached to a dispensing tip of an extrusion head. The mold may be clamped to a fixture to hold it in place, using a clamp or other means. A clamping force of less than or equal to about 10 tons will ensure office compatibility of the injection process. The mold tool is then heated to a predetermined temperature, in a step 52.

Injection molding is then performed, in a step 54. Production thermoplastic is injected from an extrusion head of the molding apparatus into the mold tool, at low, controlled pressure, and in an isothermic process. If an ultrasonic vibrator is used in the extrusion head, a thixotropic flow of thermoplastic will be injected. During the injection, pressure is monitored, such as by a pressure transducer placed in the mold cavity or sprue. A system controller can adjust the extrusion flow rate based upon pressure reading from the transducer, to maintain the pressure within a target range. The target pressure will typically be less than 2000 psi and may be set at less than 100 psi, to as low as less than 20 psi (near-zero pressure).

Filling the mold cavity will typically take about 1-2 hours. During this time, the temperature of the mold and the production thermoplastic remain approximately constant, as the plastic mold is a thermal insulator having a high thermal resistance. A temperature sensor may be placed in the mold cavity, and temperature of the thermoplastic flow, the mold tool, and/or the build environment can then be adjusted as needed to maintain isothermic conditions. Maintaining the

temperature of the mold tool at approximately the extrusion temperature of the production thermoplastic prevents premature solidification of the production thermoplastic, so that the mold cavity can fill completely before the prototype part hardens.

5 During (and prior to) the injection step 55, a vacuum may be drawn upon the mold tool. This may be done, for example, by placing the mold tool in a vacuum chamber. The vacuum will remove gases from the mold tool and the sprue, through the porosity of the mold or the vent. The vacuum will assist in pulling the injected material into the mold cavity. The vacuum will also facilitate filling the
10 mold cavity more fully and consistently than would be achieved under normal atmospheric conditions, resulting in a void-free part.

 When the mold cavity is filled, injection of material into the mold cavity is terminated and the prototype part is allowed to cool inside the mold tool, in a step 56. Cooling may take from 1 to 2 hours. Pressure may be placed on the
15 mold tool during cooling, to compensate for shrinkage of the mold tool and the prototype part. If desired, active cooling may be used to speed the cooling process. Also, monitoring of pressure in the mold cavity may be continued during cooling.

 Using the method of the present invention, a prototype plastic injection molded part can be produced within a 24-hour time period. Up to 50
20 prototype injection molded parts could be produced within 48 hours.

 It should be understood that a mold tool for use in carrying out the present invention need not be limited to a thermoplastic mold build by a deposition modeling process. Rather, any non-conductive plastic mold tool compatible with the injection process may be utilized, including, for example, mold tools formed by
25 stereolithography, thermoset mold tools, and mold tools formed by a machine-removable process (*e.g.*, CAM/CNC). A plastic material forming the mold tool may include various fillers, additives and the like.

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Although the present invention has been described with reference to preferred embodiments, workers skilled in the art will recognize that changes may be made in form and detail without departing from the spirit and scope of the invention.

- 5 For example, in one alternate embodiment, the mold tool is transparent and a photopolymer is used to form the prototype part. The photopolymer is injected into the mold cavity and cured by exposure to light. In another embodiment, thermoset reaction injection molding techniques are employed. Two or more reactant materials are mixed together to form a thermoset
- 10 resin, which is injected into the mold tool. The resin is cured to form the prototype part by applying heat to the mold tool.

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CLAIMS:

1. A method for making a prototype plastic injection molded part, comprising the steps of:
 - providing a non-conductive plastic mold tool defining a mold cavity;
 - providing a supply of production thermoplastic material;
 - heating the production thermoplastic material to an extrusion temperature lower than a heat deflection temperature of the plastic which forms the mold tool;
 - heating the mold tool to approximately the extrusion temperature;
 - injecting the production thermoplastic material into the mold cavity as a liquified ribbon of material, at a controlled pressure and in an isothermic process, so that the production thermoplastic material fills the cavity to form the prototype part; and
 - cooling the prototype part in the mold cavity to a temperature approximating room temperature.
2. The method of claim 1 and further comprising:
 - building the mold tool using a rapid prototyping technique, based on computer file data representing a desired prototype part.
3. The method of claim 1 and further comprising:
 - coating surfaces of the mold cavity with a release agent, prior to the injection step.

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4. The method of claim 1, and further comprising the step of:
monitoring pressure in the mold cavity during the injection step and
responsively adjusting the injection pressure.
5. The method of claim 4, wherein the pressure is maintained at less
than 100 psi.
6. The method of claim 4, wherein the pressure is maintained at less
than 20 psi.
7. The method of claim 1, and further comprising the step of:
clamping the mold tool to a fixture with a clamping force of less
than or equal to 10 tons, prior to the injecting step.
8. The method of claim 1, and further comprising the step of:
maintaining constant pressure on the mold tool during the cooling
step to compensate for shrinkage of the prototype part and
the mold tool.
9. The method of claim 1, wherein the mold material is injected into
the mold cavity using a melt extruder.
10. The method of claim 9, wherein the melt extruder comprises a
filament pump.
11. The method of claim 9, wherein the melt extruder comprises a piston
pump.

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12. The method of claim 1, wherein the injecting step is done in a fused deposition modeling machine.

13. The method of claim 1, wherein the production thermoplastic material is selected from a group consisting of ABS, polycarbonate, polystyrene, acrylics, amorphous polyamides, polyesters, polyphenylsulfone, polyphenylene ether, nylon, PEEK, PEAK, and blends thereof.

14. The method of claim 1, wherein the plastic mold tool is formed from a thermoplastic material comprising at least 50 weight percent of a thermoplastic selected from the group consisting of polycarbonate, polystyrene, acrylics, amorphous polyamides, polyesters, polyphenylsulfone, polysulfone, polyphenylene ether, nylon, PEEK, PEAK, poly(2-ethyl-2-oxazoline), and blends thereof.

15. The method of claim 1, wherein the injecting step is performed using a vacuum assist.

16. A method for making a prototype plastic injection molded part, comprising the steps of:

providing computer file data representing a mold tool;

building the mold tool by depositing roads of a molten thermoplastic in layers in a predetermined pattern defined by the computer file data, the mold tool defining a mold cavity;

positioning a sprue in the mold tool such that a dispensing end of the sprue is directed into the mold cavity;

attaching an inlet end of the sprue to a dispensing tip of an extrusion head;

supplying production thermoplastic material to the extrusion head,
the production thermoplastic having shrink characteristics
that approximate shrink characteristics of the thermoplastic
which forms the mold tool and a heat deflection temperature
lower than a heat deflection temperature of said
thermoplastic;

heating the production thermoplastic material to an extrusion
temperature lower than the heat deflection temperature of
the thermoplastic which forms the mold tool;

heating the mold tool to approximately the extrusion temperature;
injecting the production thermoplastic material from the extrusion
head into the mold cavity via the sprue as a liquified ribbon
of material, at a controlled pressure of less than 500 psi and
in an isothermic process, so that the production
thermoplastic fills the cavity to form the prototype part; and
cooling the prototype part in the mold cavity to a temperature
approximating room temperature.

17. The method of claim 16, and further comprising the step of:
vapor smoothing surfaces of the mold tool prior to the step of
heating the mold tool.
18. The method of claim 16, wherein the production thermoplastic is
supplied in the form of a flexible filament.
19. The method of claim 16, and further comprising the step of:
clamping the mold tool to a fixture with a clamping force of less
than or equal to 10 tons, prior to the injecting step.

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20. The method of claim 16, and further comprising the step of:
maintaining constant pressure on the mold tool during the cooling
step to compensate for shrinkage of the prototype part and
the mold tool.
21. The method of claim 16, wherein the extrusion head is a melt
extruder.
22. The method of claim 21, wherein the melt extruder comprises a
filament pump.
23. The method of claim 21, wherein the melt extruder comprises a
piston pump.
24. The method of claim 16 and further comprising the step of:
controlling the deposition of roads of the molten thermoplastic resin
so as to create an open-cell matrix in the mold tool.
25. The method of claim 16, wherein the thermoplastic forming the mold
tool comprises at least 50 weight percent of a thermoplastic selected from the group
consisting of polycarbonate, polystyrene, acrylics, amorphous polyamides,
polyesters, polyphenylsulfone, polysulfone, polyphenylene ether, nylon, PEEK,
PEAK, poly(2-ethyl-2-oxazoline), and blends thereof.
26. The method of claim 16, wherein the thermoplastic forming the
mold tool comprises a polyphenylsulfone-based resin.

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27. The method of claim 21, wherein the injecting step is done in a fused deposition modeling machine.
28. The method of claim 27, wherein the building step and the injecting step are done in the same fused deposition modeling machine.
29. The method of claim 16, wherein the thermoplastic forming the mold tool comprises a polyphenylsulfone-based resin and the production thermoplastic is ABS.
30. The method of claim 16 and further comprising the step of:
coating surfaces of the mold cavity with a release agent, prior to
heating the mold tool.
31. The method of claim 16, and further comprising the step of:
monitoring pressure in the mold cavity during the injection step and
responsively adjusting the injection pressure.
32. The method of claim 31, wherein the pressure is maintained at less than 100 psi.
33. The method of claim 31, wherein the pressure is maintained at less than 20 psi.
34. The method of claim 16, wherein the injecting step is performed using a vacuum assist.

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35. The method of claim 16, wherein ultrasonic energy is induced in the extrusion head during the injecting step creating a thixotropic flow of production thermoplastic.

36. A method for making a prototype plastic injection molded part, comprising the steps of:

providing computer file data representing a mold tool;

building the mold tool by depositing roads of a molten thermoplastic in layers in a predetermined pattern defined by the computer file data, the mold tool having two or more mating mold portions, each mold portion having a mold surface, a mating surface, and a base which supports the mold and mating surfaces;

coating the mold surfaces with a mold release agent.

assembling the two mold tool portions such that the mold surfaces define a mold cavity;

positioning a sprue in the mold tool such that a dispensing end of the sprue is directed into the mold cavity;

attaching an inlet end of the sprue to a dispensing tip of an extrusion head;

supplying production thermoplastic material to the extrusion head, the production thermoplastic having shrink characteristics that approximate shrink characteristics of the thermoplastic which forms the mold tool and a heat deflection temperature lower than a heat deflection temperature of said thermoplastic;

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heating the production thermoplastic material to an extrusion temperature lower than the heat deflection temperature of the thermoplastic which forms the mold tool;
heating the mold tool to approximately the extrusion temperature;
injecting the production thermoplastic material from the extrusion head into the mold cavity via the sprue as a liquified ribbon of material, at a controlled pressure of less than 500 psi and in an isothermic process, so that the production thermoplastic material fills the cavity to form the prototype part; and
cooling the prototype part in the mold cavity to a temperature approximating room temperature.

37. The method of claim 36, and further comprising the step of:
vapor smoothing the mold surfaces of the mold tool prior to the assembling step.
38. The method of claim 36, and further comprising the step of:
liquid smoothing the mold surfaces of the mold tool prior to the assembling step.
39. The method of claim 36, and further comprising the step of:
clamping the mold tool to a fixture with a clamping force of less than or equal to 10 tons, prior to the injecting step.

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40. The method of claim 36, and further comprising the step of:
maintaining constant pressure on the mold tool during the cooling
step to compensate for shrinkage of the prototype part and
the mold tool.
41. The method of claim 36, wherein the extrusion head is a melt
extruder.
42. The method of claim 41, wherein the melt extruder comprises a
filament pump.
43. The method of claim 41, wherein the melt extruder comprises a
piston pump.
44. The method of claim 36 and further comprising the step of:
controlling the deposition of roads of the molten thermoplastic resin
so as to create an open-cell matrix in the mold tool.
45. The method of claim 36, wherein the thermoplastic forming the
mold tool comprises at least 50 weight percent of a thermoplastic selected from the
group consisting of polycarbonate, polystyrene, acrylics, amorphous polyamides,
polyesters, polyphenylsulfone, polysulfone, polyphenylene ether, nylon, PEEK,
PEAK, poly(2-ethyl-2-oxazoline), and blends thereof.
46. The method of claim 36, wherein the thermoplastic forming the
mold tool comprises a polyphenylsulfone-based resin.

47. The method of claim 36, wherein the injecting step is done in a fused deposition modeling machine.
48. The method of claim 47, wherein the building step and the injecting step are done in the same fused deposition modeling machine.
49. The method of claim 48, wherein the production thermoplastic is supplied to the extrusion head in the form of a flexible strand.
50. The method of claim 36, wherein the thermoplastic comprises a polyphenylsulfone-based resin and the production thermoplastic is ABS.
51. The method of claim 36, and further comprising the step of:
monitoring pressure in the mold cavity during the injection step and
responsively adjusting the injection pressure.
52. The method of claim 51, wherein the pressure is maintained at less than 100 psi.
53. The method of claim 51, wherein the pressure is maintained at less than 20 psi.
54. The method of claim 36, wherein the injecting step is performed using a vacuum assist.
55. The method of claim 36, wherein ultrasonic energy is induced in the extrusion head during the injecting step creating a thixotropic flow of production thermoplastic.

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56. A method for making a prototype plastic injection molded part, comprising the steps of:

providing a non-conductive plastic mold tool defining a mold cavity;
injecting a production thermoplastic material into the mold cavity as a liquified ribbon of material, in an adiabatic process, so that the production thermoplastic material fills the cavity;
and
slowly cooling the production thermoplastic material in the mold cavity to form the prototype part.

57. The method of claim 56, wherein the production thermoplastic material is supplied in the form of a flexible filament.

58. A method for making a prototype plastic injection molded part, comprising the steps of:

providing a non-conductive, transparent plastic mold tool defining a mold cavity;
providing a supply of a photopolymer, the polymer having shrink characteristics that approximate shrink characteristics of the plastic which forms the mold tool;
heating the polymer to an extrusion temperature lower than the heat deflection temperature of the plastic which forms the mold tool;
heating the mold tool to approximately the extrusion temperature;
injecting the polymer into the mold cavity as a liquid at a controlled pressure of less than 2000 psi and in an isothermic process, so that the polymer fills the cavity;

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curing the polymer in the mold cavity by exposing the polymer to light, thereby forming the molded prototype part; and cooling the molded prototype part in the mold cavity to a temperature approximating room temperature.

59. A method for making a prototype plastic injection molded part, comprising the steps of:

providing a non-conductive plastic mold tool defining a mold cavity, the mold tool having a heat deflection temperature; providing a supply of two or more reactant materials which form a thermoset resin when reacted together;

mixing the reactant materials together;

injecting the reactant materials into the mold cavity as a liquified ribbon of material, at a controlled pressure of less than 2000 psi, so that the reactant materials fill the cavity;

heating the reactant materials in the mold cavity to form the molded prototype part; and

cooling the molded prototype part in the mold cavity to a temperature approximating room temperature.

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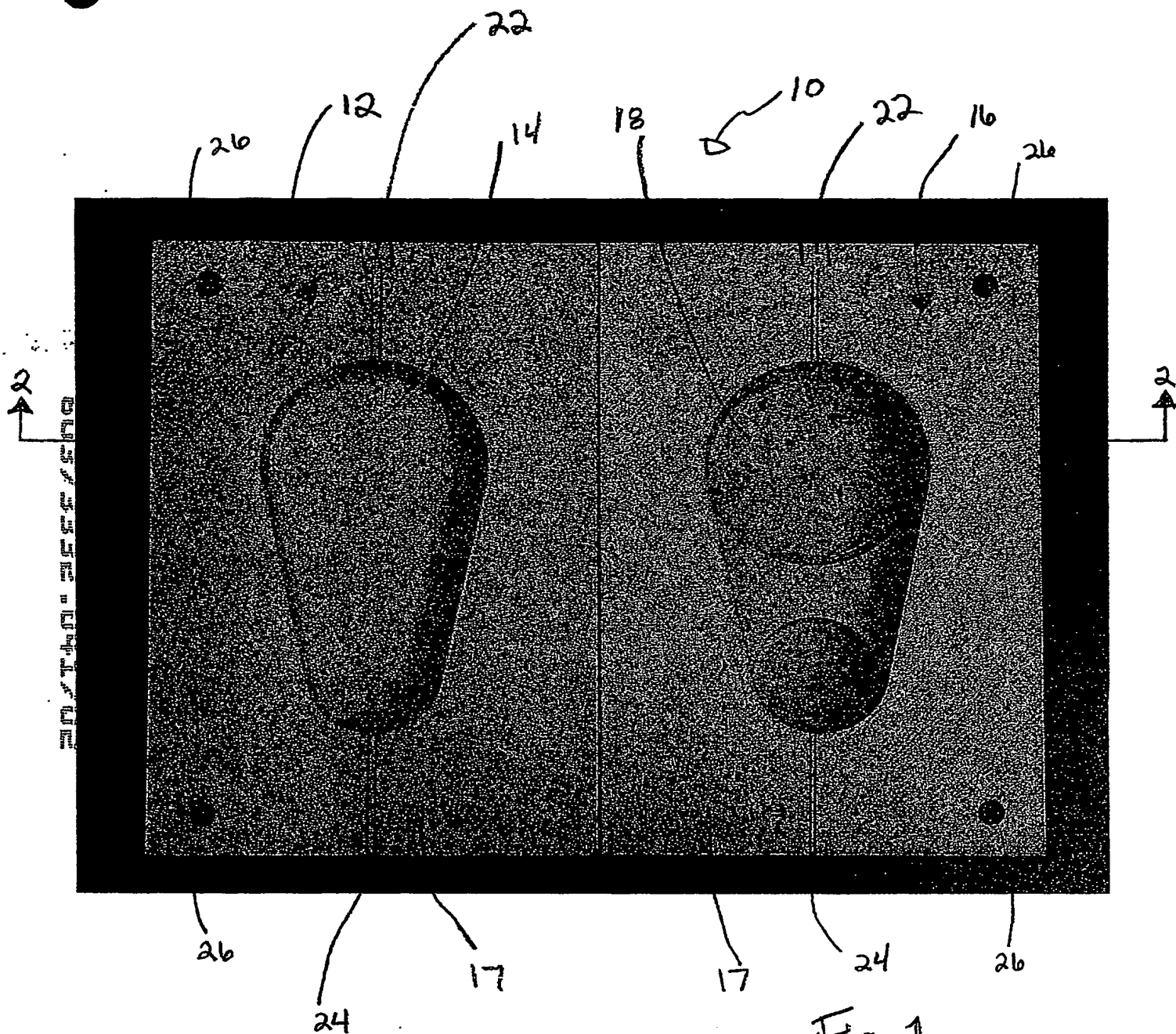


Fig. 1

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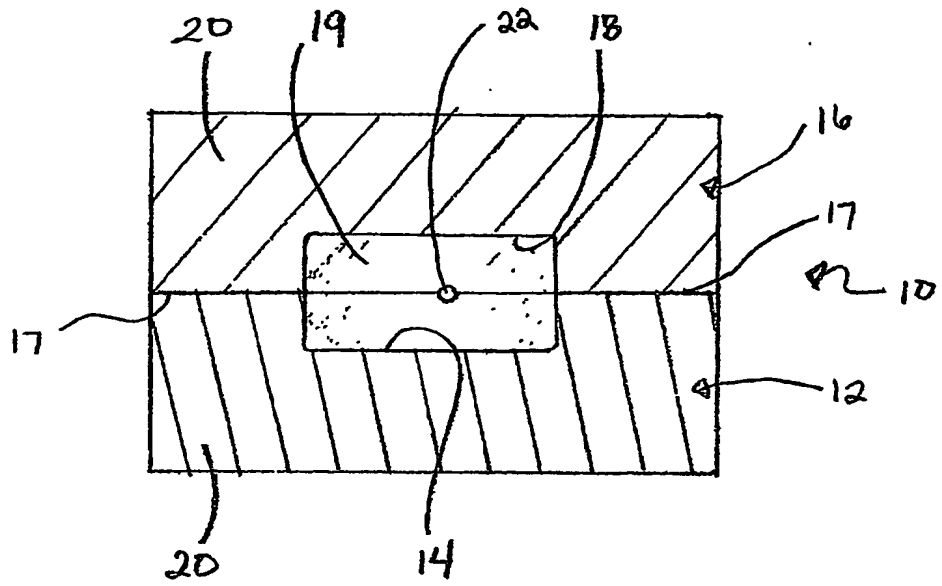
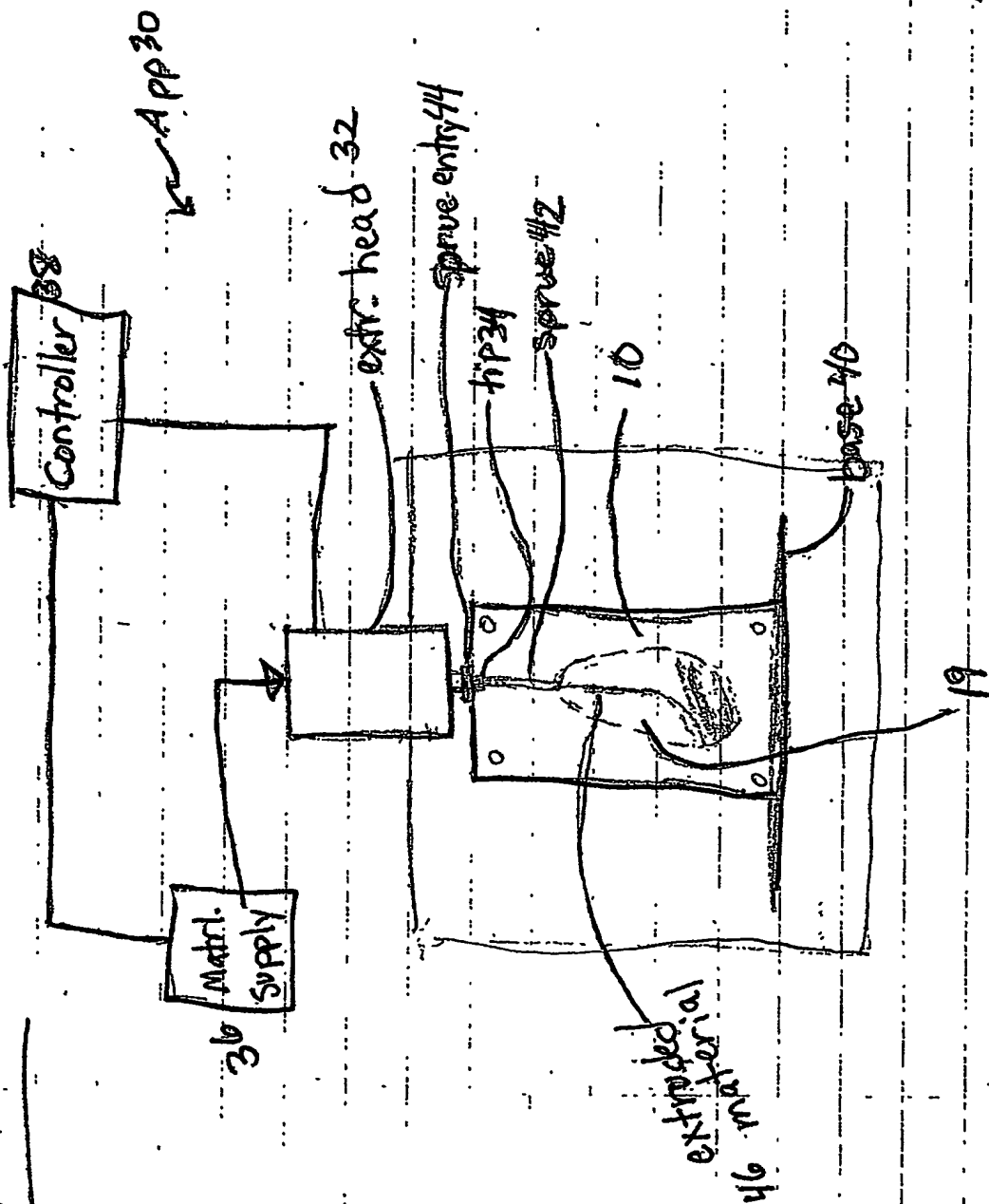


Fig. 2

FIG. 3



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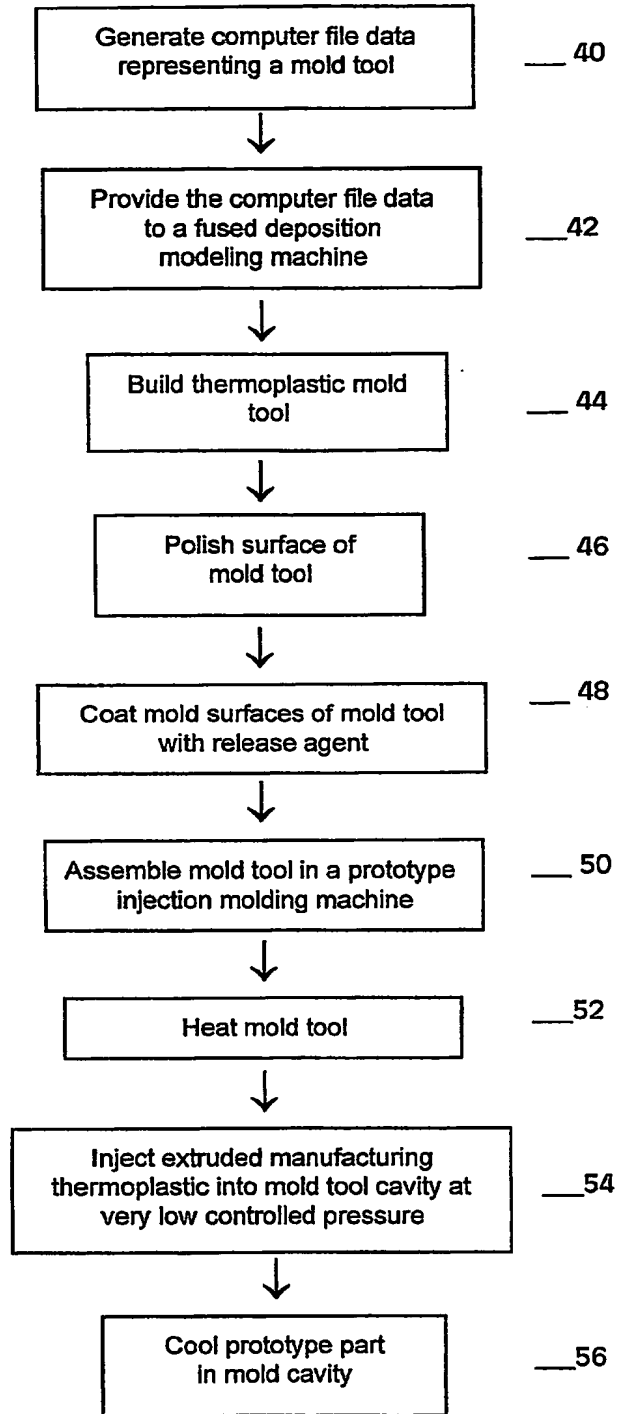


Fig. 4